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Energy supply, its demand and security issues for developed and emerging economies

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Abstract

Energy is inevitable for human life and a secure and accessible supply of energy is crucial for the sustainability of modern societies. Continuation of the use of fossil fuels is set to face multiple challenges: depletion of fossil fuel reserves, global warming and other environmental concerns, geopolitical and military conflicts and of late, continued and significant fuel price rise. These problems indicate an unsustainable situation. Renewable energy is the solution to the growing energy challenges. Renewable energy resources such as solar, wind, biomass, and wave and tidal energy, are abundant, inexhaustible and environmentally friendly.

This article provides an overview of the current and projected energy scene. Five countries, that presently have a significant impact on global energy situation, have been studied in this work. These include China, India, Russia, UK and USA. Together the present energy budget of these countries is roughly half that of the globe. Four of the above five countries that are discussed in this work—China, India, UK and USA are all net importers of energy and are heavily dependent on imports of fuel to sustain their energy demands. Their respective local oil reserves will only last 9, 6, 7 and 4 years, respectively. China, the emerging economy in the world, is however making exemplary development in renewable energy—in 2004 renewable energy in China grew by 25% against 7–9% growth in electricity demand. While in the same year, wind energy in China saw a growth of 35%. China is also leading the global solar thermal market as it has already installed solar collectors over 65 million square meters, accounting for more than 40% of the world's total collector area.

This article quantifies the period of exhaustion of the current major energy sources, i.e. coal, oil, gas and nuclear fissile material. Projected demand for energy is also presented and a feasibility of switch over to renewable energy is discussed. The article also presents the size of respective wind- and solar farms that would be required for each of the five countries under discussion to meet their year 2020 energy demands. It has been found that to meet 50% of the total energy demands the proposed

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area for collection of solar and wind energy by means of ultra-large scale farms in fact will occupy a mere fraction of the available land and near-offshore area for the respective countries, e.g. a solar PV electricity farm of 61 km^2 for China represents 0.005% of the Gobi desert. Likewise, the 26 and 36 km^2 PV farm area, respectively, required for India and the US represents 0.01% and 0.014% land area of Rajasthan and Baja deserts. The above areas required for the farms may be further split to form a cluster of smaller energy farms.

Keywords: Renewable energy; Solar and wind power; Energy security; Sustainable energy supply

Contents

1. Introduction

Energy drives human life and is extremely crucial for continued human development. Throughout the course of history, with the evolution of civilizations, the human demand for energy has continuously risen. The global demand for energy is rapidly increasing with increasing human population, urbanization and modernization. The growth in global energy demand is projected to rise sharply over the coming years. The world heavily relies on fossil fuels to meet its energy requirements—fossil fuels such as oil, gas and coal are providing almost 80% of the global energy demands. On the other hand presently renewable energy and nuclear power are, respectively, only contributing 13.5% and 6.5% of the total energy needs. The enormous amount of energy being consumed across the world is having adverse implications on the ecosystem of the planet. Fossil fuels, the main

source of energy, are inflicting enormous impacts on the environment. Climatic changes driven by human activities, in particular the production of Greenhouse Gas emissions (GHG), directly impact the environment. According to World Health Organization (WHO) as many as 160,000 people die each year from the side-effects of climate change and the numbers could almost double by 2020. These side effects range from malaria to malnutrition and diarrhea that follow in the wake of floods, droughts and warmer temperatures [1].

Presently employed energy systems will be unable to cope with future energy requirements—fossil fuel reserves are depleting, and predominantly the developed countries employ nuclear power. Fossil fuel and nuclear energy production and consumption are closely linked to environmental degradation that threatens human health and quality of life, and affects ecological balance and biological diversity. It is therefore clear that if the rapidly increasing global energy needs are to be met without irreparable environmental damage, there will have to be a worldwide drive to exploit energy systems that should not endanger the life of current and future generations and should not exceed the carrying capacity of ecosystems. Renewable energy sources that use indigenous resources have the potential to provide energy services with almost nil emissions of both air pollutants and greenhouse gases.

Renewable energy sources such as solar energy, wind power, biomass and geothermal energy are abundant, inexhaustible and widely available. These resources have the capacity to meet the present and future energy demands of the world as indicated in Fig. 1. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute to securing long-term sustainable energy supplies, help reduce local and global environmental impacts and provide commercially attractive options to meet specific energy service needs, particularly in developing countries and rural areas, creating new employment opportunities. The cost of energy generated from these renewable resources is significantly coming down while the cost of fossil fuel produced energy is in an increasing mode. Over the last two decades solar and wind energy systems have experienced rapid growth. This is being supported by several factors such as declining

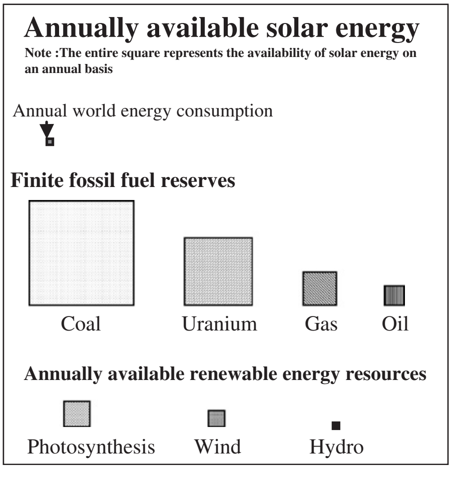


Fig. 1. Potential of various renewable energy sources as compared to global energy needs.

capital cost; declining cost of electricity generated and continued improvement in performance characteristics of these systems. The fossil fuel and renewable energy prices, and social and environmental costs of each, are heading in opposite directions, and the economic and policy mechanisms needed to support the widespread dissemination and sustainable markets for renewable energy systems are rapidly evolving.

This article aims to present the challenges facing secure and sustainable supply of energy. Energy scenarios of five major energy consuming countries of the world i.e. China, India, Russia, UK and USA have been presented. These countries were selected for this study in view of the fact that they constitute 45% of the global population and consume 49% of the total energy consumption of the world as shown in Table 1. The role of India and China—world emerging economies—is set to become even more crucial in the days to come.

2. Human civilization and energy use

Energy is one of the most basic of human needs. The accomplishments of civilization have largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity. Providing adequate and affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards worldwide.

With the exception of humans every organism's total energy demand is its supply of energy in the form of food derived directly or indirectly from sun's energy. For humans the energy requirements are not just for heating, cooling, transport and manufacture of goods but also those related to agriculture. However, the ingenuity of humans is such that throughout history there has been an exponential increase in the carrying capacity of land, particularly during the past few decades. Based on information obtained from Southwood [2] and Simon [3], Table 2 presents the progression of the agricultural land carrying capacity. In Table 2 the term 'PhytoFarming' was introduced. This hydroponic technique uses artificial light for very intense crop production and has been in use since early 1990s. Based on the output of such farming Simon [3] has estimated the ultimate carrying capacity for planet Earth to be 500 billion! What is apparent that in the long-term future availability of energy will increasingly become linked with agriculture production.

The estimates of world population produced by the UN suggest that six and a half billion people were living in 2005 and that the next 45 years will see a further increase of 40% to 9.1 billion.

Other estimates suggest that the world population is expected to double by the middle of this century [4]. Most of the population increase will take place in developing countries. Three years ago the United Nations Population Division had estimated the 2050 population at 8.1 billion. This rapid increase will take place mostly in the developing world. With the growing world population and people's innate aspirations for improved life, a central and collective global issue in the new century will be sustaining economic growth within the constraints of our planet's limited natural resources while at the same time preserving our environment—the so-called global sustainability issue. The population growth and the inevitable need to expand economic output would place enormous demands on our stock of natural and environmental resources. To frame it in a better perspective, global economic output doubles approximately every 30 years, accompanied by an increased demand on our natural resources and a greater impact on the environment. But it is not simply population growth that makes the future compounded.

Table 1
Population, economic, energy and environmental dynamics for five key nations and the world for 2004

	India	China	Russian Federation	UK	USA	ROW	World	Energy use for the five key nations as a fraction of world energy consumption
Population (million people)	1080.3	1306.3	143.4	60.4	295.7		6446.1	45
Population growth (%)	1.40	0.58	−0.40	0.28	0.92		1.14	
GDP/Capita (k$)	3.1	5.6	9.8	29.6	40.1		8.8	
GDP growth rate (%)	6.2	9.1	6.7	3.2	4.4		4.9	
CO_2 emissions (metric tonne/capita)	1.2	2.7	10.0	2.5	5.4			
Energy consumption/capita (kg oil equivalent)	486	830	3963	3930	7937			
Energy consumption/capita (kWh)	3969	9683	46,235	45,850	92,598			
Total energy consumption (million tonne oil equivalent)	376	1386	669	227	2332		10,224	
All energy quantities below are in TWh								
Total energy consumption	4384	16,172	7800	2647	27,202	61,079	1,19,285	49
Electricity consumption	575	1940	1018	359	3989	7832	15,714	50
Coal consumption	2389	11,164	1236	445	6584	10,596	32,412	67
Oil consumption	1392	3600	1499	943	10,939	25,577	43,950	42
Gas consumption	337	410	4221	1029	6790	15,451	28,238	45
Nuclear consumption	44	132	378	211	2192	4326	7284	41
Renewable energy consumption	19	74	40	2	60	440	634	31

Table 2
Progression of agricultural land carrying capacity

Mode of agriculture	Number of humans supported per km^2
Hunter–gatherer	1
Domesticated animals	2
Shifting cultivation, S.E Asia	10
Medieval agriculture (1200 CE, UK)	20
Intense tropical peasant agriculture (New Guinea)	50
Modern agriculture, UK	150
Modern agriculture, USA	500
Modern agriculture, Japan	2,500
Phytofarming	1,000,000

Urbanization is occurring even faster, as impoverished people seek opportunity by migrating to already crowded cities. These factors will place demands on increased energy output as well, as per capita energy consumption will rise with economic growth. For instance, assuming that sometime before the end of the 21st century the global average per capita energy consumption reaches half that of US today (which is approximately the same as Eastern Europe in today's terms) and former Soviet Union today, the global annual energy consumption will be five times the present value.

Since, the utilization of energy is essential to the survival of human civilization, the challenge for the 21st century is to develop methods of generating and using energy that meet the needs of growing global population while protecting the planet.

3. Transition in energy use

Energy, being a crucial feature of human life, has evolved to match with contemporary human development and requirements. It has been estimated that the global population in 1800 was approximately 1 billion, an uncertain estimate given that the first population census had just been introduced around that time in Sweden and England. Estimates of past energy use based on historic statistics and current energy use in rural areas of developing countries suggest that energy use per capita typically did not exceed some 20 GJ as a global average. Over 200 years later, the global population has risen by a factor of 6 while the per capita energy consumption is estimated to have risen by a factor of 20 [5]. A 20-fold increase, far in excess of world population growth, constitutes the first major energy transition, a transition from penury to abundance. This transition is far from complete and is characterized by persistent spatial and temporal heterogeneity. This transition in energy quantities is also closely linked to corresponding energy transition in terms of energy structure as well as in terms of energy quality. Fig. 2 shows an inherent link between prosperity and energy use. Given the past record of developed countries in their profligate use of energy, developing nations tend to mimic their energy consumption pattern to match those of the developed nations. What Fig. 2 does is it helps us increase our understanding of the expected global energy consumption increase as nations across the world target their quest for increased prosperity.

One of the most significant transitions in global energy systems is that of decarbonization, an increase in energy quality. Considering the case of fossil fuels, the

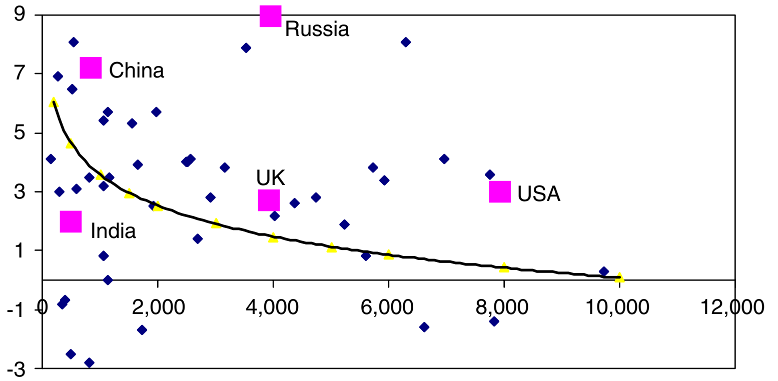


Fig. 2. Per cent increase in energy consumption versus kg oil consumption/capita for 50 countries. Curve shown is based on [2].

dominating energy resource over the course of human history, each successive transition from one source to another—from wood to coal, from coal to oil—has entailed a shift to fuels that were not only harnessed and transported more economically, but also had a lower carbon content and higher hydrogen content. It is also evident that at each step greater energy density is being achieved. The third wave of decarbonization is now at its threshold, with natural gas use growing fastest, in terms of use, among the fossil fuels. The fourth wave, the production and use of pure hydrogen, is certainly on the horizon. Its major drivers are technological advances, renewed concern about the security and price of oil and gasoline, and growing pressure to address local air pollution and climate change.

4. Global energy overview

4.1. Energy modes

There are various forms of energy that are employed worldwide to meet human energy requirements. These different forms of energy can be widely categorized into three types: fossil fuel, nuclear and renewables.

4.1.1. Fossil fuel energy

Historically, fossil fuels, in their various forms, have been the main source of energy supply and have served the human energy needs for thousands of years. According to International Energy Association's 2002 statistics almost 80% of the world primary energy demands are met by fossil fuels [6]. Wood and coal have been serving society to meet energy needs for a long time. In the beginning, this energy source was very stable and sustainable. Forests and coal resources were in abundance and were sufficient to meet energy demands. However, as human creativity exceeded expectations, producing a more efficient energy technology based on coal and then on oil was needed. Especially, with the advent of industrial revolution in 19th century, fossil fuels saw their refined liquid phase, oil that is more efficient than their traditional solid phase counterparts (wood and coal). More recently, world became familiarized with gaseous phase of fossil fuels that is ever

more efficient. This energy transition from wood to coal to oil to natural gas has been the different phases of traditional fossil fuels.

4.1.2. Nuclear power

Nuclear power is the main source of energy in some of the major developing countries in the world and contributes to almost 7% of the global energy demands. Nuclear energy has played a major role in reducing the world's use of oil for electricity generation over the past three decades. As of December 2003, there were 440 nuclear power plants operating in 31 countries around the world [7]. Nuclear power, however, faces the following four critical challenges as highlighted by Sackett [8].

a. *Cost*: Any power source must make sense in a competitive market. Nuclear power suffers from the fact that plants have been built in with varying designs. Further, each one of these plants has to satisfy safety requirements, which have continually changed through the early years of development. The designs therefore resulted in increased capital costs and very large staffing requirements, driving up the cost of electricity. The nuclear power is twice as expensive as generating electricity from gas or wind. It has also been shown that energy conservation measures are around seven times more economical than nuclear power. For this reason even the nuclear industry does not want to build reactors without government assistance.

b. *Radioactive waste*: Nuclear power has serious environmental implications. The claim that nuclear power is 'carbon free' does not hold water. It has been estimated that the emissions associated with the latter source are a third of gas-fired emissions. This figure is expected to rise even further as poorer uranium ores are used (see Table 6 that shows exhaustion time scales for uranium).

Nuclear power plants produce radioactive gases. These gases are to be contained in the operation of the plant. If these gases are released into the air, major health risks can occur. Nuclear plants use uranium as a fuel to produce power. The mining and handling of uranium is very risky and radiation leaks can occur. The third concern of nuclear power is the permanent storage of spent radioactive fuel. This nuclear fuel is toxic and its handling and disposal is an ongoing environmental issue for centuries. It is also important to realize that nuclear waste remains dangerous for 240,000 years and that is 20 times longer than the entire history of civilisation.

c. *Safety*: The nuclear plants in developed countries have become increasingly complex, in part, ironically, because of the addition of many safety systems. Although, existing nuclear power plants in developed countries are considered to be safe, yet, there are reactors operating in many countries of the former Soviet Union that must be monitored carefully to avoid another accident on the scale of Chernobyl. Many have no containment vessels and inadequate emergency core cooling systems. Such issues need to be addressed.

d. *Proliferation of weapons material*: *A* requirement for substantial growth of nuclear power is to prevent the proliferation of material that could be diverted to use in nuclear weapons.

Nuclear power, hence, is not only in a state of stagnancy over the last many years but is also facing a downward trend. The commitment to new reactor sitings and development, however, has stalled. Since 1995, opening of new nuclear power plants occurred only in France, the Czech Republic, Brazil and in Asia. There has been a de facto moratorium on new nuclear power in most of the world since 1980, with phase out decisions pronounced in Sweden, Germany, Switzerland, Spain, Belgium and the Netherlands [9]. Germany,

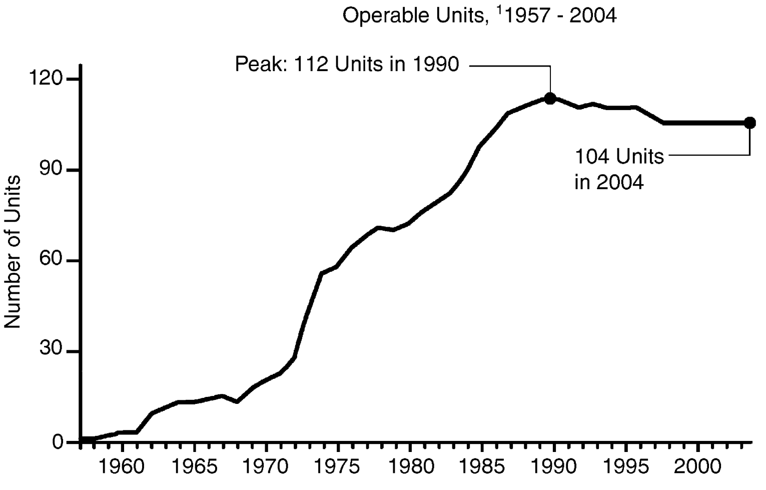


Fig. 3. Number of operating nuclear power stations within USA.

a leading customer of nuclear power, for example, took major steps in November 2003 towards ending its nuclear power programme when it shutdown the first of its 19 atomic power stations. The shutdown followed an agreement signed with the industry in the year 2000 to close all the nuclear power plants by 2025. Several other European countries are preparing to follow Germany's lead, with both Belgium and Sweden announcing nuclear phase-out plans [10]. Similarly, in US, the nuclear power capacity has decreased since 1990 as shown in Fig. 3 [11].

Finally, due to its very nature nuclear power attracts unwarranted publicity and raises negative passion at public enquiries. This has a knock on effect on the time it takes for construction of new build. To quote an example within Britain, the last reactor to be built, the one at Sizewell took 15 years.

4.1.3. Renewable energy

Renewable energy as the name implies is the energy obtained from natural sources such as wind power, solar energy, hydropower, biomass energy and geothermal energy. Renewable energy sources have also been important for humans since the beginning of civilization; Biomass, for example, has been used for heating, cooking and steam production; wind has been used for moving ships; both hydropower and wind have been used for powering mills to grind grains. Renewable energy sources that use indigenous resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Renewable energy resources are abundant in nature. They are presently meeting almost 13.5% of the global primary energy demands and are acknowledged as a vital and plentiful source of energy that can indeed meet entire world's energy demand.

Renewable energy sources have enormous potential and can meet many times the present world energy demand. They can enhance diversity in energy supply markets, secure long-term sustainable energy supplies, and reduce local and global atmospheric emissions. They can also provide commercially attractive options to meet specific needs for energy services (particularly in developing countries and rural areas), create new employment opportunities, and offer possibilities for local manufacturing of equipment.

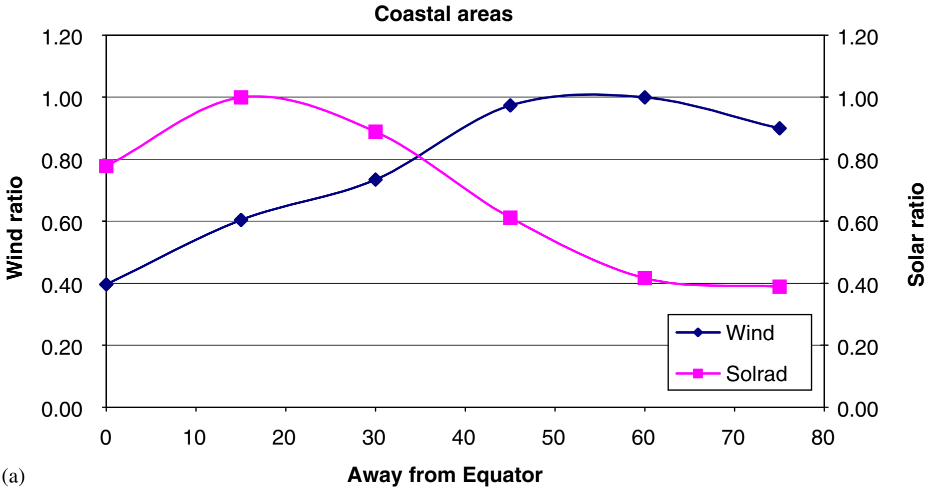
Renewable sector is now growing faster than the growth in overall energy market. Approximately US$22 billion was invested in renewable energy worldwide in 2003. Annual investment in renewable energy has grown almost fourfold from $6 billion in 1995, while cumulative investment since 1995 is of the order of $110 billion. The 2003 investment shares in the renewables sector was roughly 38% for wind power, 24% for solar PV, and 21% for solar thermal hot water. Small hydropower, biomass power generation, and geothermal power and heat made up the remaining 17%. Total renewable power capacity stood at roughly 140 GW as of 2003, excluding large hydro. This represents slightly less than 4% of the world's total electric power capacity. About 40% of total renewable power capacity is installed in developing countries. Worldwide, wind capacity increased by 26% and grid-connected solar PV capacity increased by an incredible 50% (365 MW) in 2003. These growth rates far outpace those for traditional electric power, currently 1–3% in most countries, except China, where traditional power capacity is growing at rates of 7–9% [12]. Some long-term scenarios postulate a rapidly increasing share of renewable technologies made up of solar, wind, geothermal, modern biomass, as well as the more traditional hydro. Under such a scenario, renewables could reach up to 50% of the total share of mid-21st century with appropriate policies and new technology developments. Fig. 4 shows the average profile of available solar and wind energy as a function of latitude. We may observe that the latter two forms of renewable energy are complementary and thus, while nations close to equator may be blessed with solar power, wind energy has good prospects for nations closer to the poles. An appropriate combination of the above two sources would obviously be a feasible solution for any given nation.

4.2. Growing energy demand

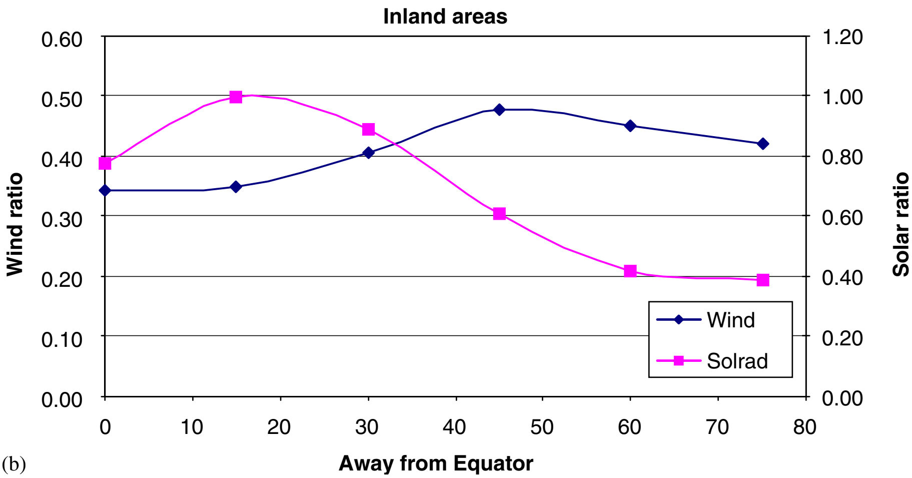
The demand for the provision of energy is increasing worldwide and will continue to rise due to rapidly rising human population and modernisation trends across the world. The International Energy Outlook projects strong growth for worldwide energy demand up to 2025 [13]. Total world consumption of marketed energy is expected to expand by 57% over the 2002–2025 time period. In the *IEO2005* mid-term outlook, the emerging economies account for nearly two-thirds of the increase in world energy use, surpassing energy use in the mature market economies for the first time in 2020. In 2025, energy demand in the emerging economies is expected to exceed that of the mature market economies by 9%. Much of the growth in energy demand among the emerging economies is expected to occur in emerging Asia, which includes China and India; demand in this region is projected to more than double over the forecast period. Primary energy consumption in the emerging economies as a whole is projected to grow at an average annual rate of 3.2% up to 2025. In contrast, in the mature market economies—where energy consumption patterns are well established—energy use is expected to grow at a much slower average rate of 1.1% per year over the same period. In the transitional economies of Eastern Europe and the former Soviet Union, growth in energy demand is projected to average 1.6% per year.

4.3. Energy related challenges

The present energy situation, led by fossil fuels, has four major concerns: depletion of fossil fuel reserves, global warming, energy security concerns and rising energy cost.



(a)



(b)

Fig. 4. Solar and wind energy potential with respect to geographical latitude. Note: available energy is expressed as a fraction of the maximum potential.

4.3.1. *Fossil fuels depletion*

World ultimate conventional oil reserves are estimated at 2000 billion barrels. This is the amount of production that would have been produced when production eventually ceases. The global daily consumption of oil equals 71.7 million barrels. Different countries are at different stages of their reserve depletion curves. Some, such as United States, are past their midpoint and are in terminal decline, where as others are close to midpoint such as UK and Norway. However, the five major Gulf producers—Saudi Arabia, Iraq, Iran, Kuwait and United Arab Emirates—are at an early stage of depletion and can exert a swing role, making up the difference between world demand and what others can supply.

The expert consensus is that the world's midpoint of reserve depletion will be reached when 1000 billion barrels of oil have been produced—that is to say, half the ultimate

Table 3
Various projections of global ultimate conventional oil reserves and peak year (billions barrels)

Author	Affiliation	Year	Estimated ultimate reserves	Peak year
Hubert	Shell	1969	2100	2000
Bookout	Shell	1989	2000	2010
Mackenzie	Researcher	1996	2600	2007–2019
Appleby	BP	1996		2010
Invanhoe	Consultant	1996		2010
Edwards	University of Colorado	1997	2836	2020
Campbell	Consultant	1997	1800–2000	2010
Bernaby	ENI	1998		2005
Schollenberger	Amoco	1988		2015–2035
IEA	OECD	1998	2800	2010–2020
EIA	DOE	1998	4700	2030
Laherrere	Consultant	1999	2700	2010
USGS	International Department	2000	3270	
Salameh	Consultant	2000	2000	2004–2005
Deffeyes	Princeton University	2001	1800–2100	2004

reserves of 2000 billion barrels. It is estimated that around 1000 billion barrels have already been consumed and 1000 billion barrels of proven oil reserves are left in the world. It was reported in year 2003, that reserve to production ratio of fossil fuels for North America, Europe and Eurasia, and Asia Pacific were 10, 57 and 40 years, respectively [14]. Research conducted at the University of Uppsala in Sweden claims that oil supplies will peak soon after 2010, and gas supplies not long afterwards, making the price of petrol and other fuels rocket with potentially disastrous economic consequences unless people have moved to alternatives to fossil fuels [15]. Similarly, a growing number of opinions among energy experts suggest that global conventional oil production will probably peak sometime during this decade, between 2004 and 2010 as shown in Table 3. Declining oil production will cause a global energy gap, which will have to be filled by unconventional and renewable energy sources [16].

4.3.2. Global warming

There is an intimate relationship between energy and environment. The production and use of all energy sources results in undesirable environmental effects, which vary based on the health of the existing ecosystem, the size and health of the human population, energy production and consumption technology, and chemical properties of the energy source or conversion device. A shorthand equation for the environmental impacts of energy production and use has been provided by Solomon, as following [9]:

$$I = PAT,$$

where I is the environmental impact; P the size of human population; A the affluence of the population (e.g. per capita income and/or energy use); and T the Technology (e.g., energy efficiency, emission rate of air and water pollution).

The balance of evidence suggests that there is a discernible human influence on global climate. Figures on carbon dioxide (CO_2) illustrate how the waste deluge has grown. Global CO_2 production climbed to 23.9 billion tons in 2001 from 21.5 billion tons in 1990.

In business as usual scenario CO_2 level is projected to rise to as much as 37.1 billion tonnes by the year 2025 as indicated in Fig 5. Global mean temperature is forecast to rise by between 1 °C and 4.5 °C by 2100, with best estimates somewhere between 2 and 3 degrees [4]. All projections produce rates of warming that are greater than those experienced in the last 10,000 years. Sea level is projected to rise by about 50 cms by 2100 (with a range of 15–95 cms), due to thermal expansion of the oceans and melting glaciers and ice sheets. Temperature and sea level changes will not be globally uniform. Land areas, particularly at high latitudes, will warm faster than the oceans, with a more vigorous hydrological cycle potentially affecting the rate and scale of various extreme events such as drought, flood and rainfall. Impacts on natural and semi-natural ecosystems, agriculture, water resources, human infrastructure and human health are subject to many uncertainties, but all will be subject to stresses which will exacerbate stresses from other sources such as land degradation, pollution, population growth and migration, and rising per capita exploitation of natural resources.

Climate change is responsible for huge economical consequences. Between the 1960s and the 1990s, the number of significant natural catastrophes such as floods and storms rose ninefold, and the associated economic losses rose by a factor of nine. Figures indicate that the economical losses as a direct result of natural catastrophes over 5 years between 1954 and 1959 were US$35 billion while between 1995 and 1999 these losses were around US$340 billion [17]. Natural catastrophes associated to global warming killed over 190,000 people in 2004, twice as many as in 2003, with an economic cost of US$145 billions. The August 2005 hurricane Katrina is being held responsible for more than 1000 human lives. Hurricane Katrina caused at least $125 billion in economic damage and could cost the insurance industry up to $60 billion in claims. That is significantly higher than the previous record-setting storm, Hurricane Andrew in 1992, which caused nearly $21 billion in insured losses in today's dollars [18]. Some economists believe, the physical and psychological damage caused by Katrina is likely to reverberate across the global economy in ways that will curb growth well in 2006. Katrina shut down large portions of

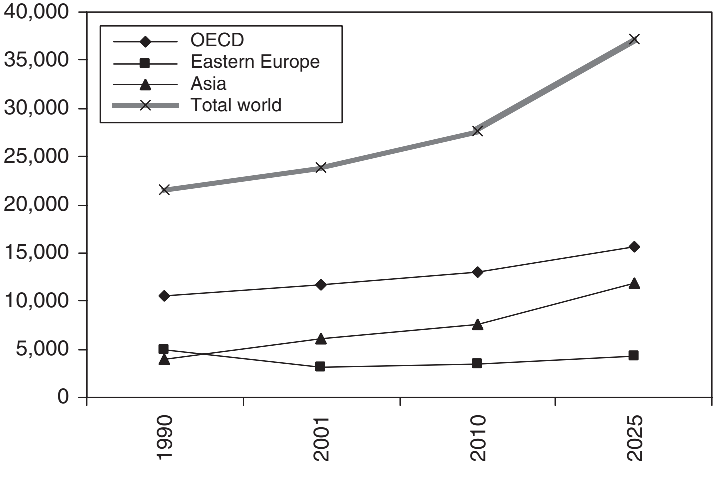


Fig. 5. CO_2 emissions in millions of tones.

oil and gas production in the Gulf of Mexico at a time when worldwide energy output was already stretched thin. While the storm's impact was most acute in the United States, it also sent fuel costs higher around the globe, squeezing consumers in Europe and Asia [19].

4.3.3. Energy security

The economies of all countries, and particularly of the developed countries, are dependent on secure supplies of energy. Energy security means consistent availability of sufficient energy in various forms at affordable prices. These conditions must prevail over the long-term if energy is to contribute to sustainable development. Attention to energy security is critical because of the uneven distribution of the fossil fuel resources on which most countries currently rely. The energy supply could become more vulnerable over the near term due to the growing global reliance on imported oil. Of the trillion barrels of the proven oil reserves currently estimated, 6% are in North America, 9% in Central and Latin America, 2% in Europe, 4% in Asia Pacific, 7% in Africa, 6% in the Former Soviet Union. Presently 66% of global oil reserves are distributed amongst Middle Eastern countries: Saudi Arabia (25%), Iraq (11%), Iran (8%), UAE (9%), Kuwait (9%), and Libya (2%) [20]. The oil and gas reserves in non-Middle East countries are being depleted more rapidly than those of Middle East producers. If production continues at present rate, many of the largest, non-Middle Eastern, producers in 2002, such as Russia, Mexico, US, Norway, China and Brazil will cease to be relevant players in the oil market in less than two decades. At that point, the Middle East will be the only major reservoir of abundant crude oil—within 20 years or so about four-fifths of oil reserves could be in the hands of the Middle Eastern countries as shown in Fig. 6. Many of these leading oil producing countries are politically unstable.

The Middle Eastern region as a whole has quite a volatile geopolitical situation as it has seen a number of conflicts over past few decades. The oil factor cannot be ruled out in some of the major conflicts in the area. There are serious reservations regarding security of oil; production and supply channels of some of the Middle Eastern countries like Iraq, that is the second largest oil-producing country in the world, are regarded as the legitimate targets of radical elements because of various internal and external conflicts.

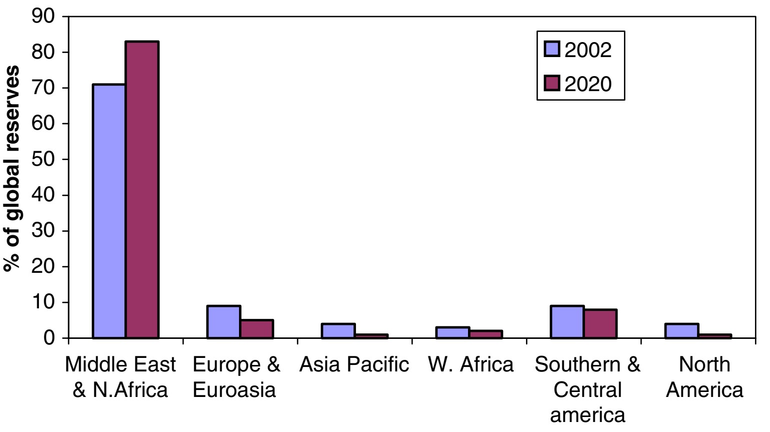


Fig. 6. BP statistical review of world energy: world reserves for 2002 and 2020.

Getting oil from the well to the refinery and from there to the service station involves a complex transportation and storage system. Millions of barrels of oil are transported every day in tankers, pipelines and trucks. This transportation system has always been a possible weakness of the oil industry, but it has become even more so in the present volatile geopolitical situation, especially in the Middle East region. The threats of global terrorism have made the equation more complex. Tankers and pipelines are quite vulnerable targets. There are approximately 4,000 tankers employed, and each of them can be attacked in the high seas and more seriously while passing through narrow straits in hazardous areas. Pipelines, through which about 40% of world's oil flows, are no less vulnerable and due to their length, they are very difficult to protect. This makes pipelines potential targets for terrorists.

The above analysis indicates that the present situation is not sustainable, and that it cannot guarantee secure supplies of energy. The psychological effects are felt already, as demonstrated by significant fluctuation of oil prices over the recent years, due to relatively minor events in the Middle East. A more serious event, such as sinking of an oil tanker in one of the busy shipping lanes or disruption of a major pipeline, would have a much more catastrophic effect on the oil prices and, hence, the world economy.

4.3.4. Rising oil prices

The rise in oil price has made headlines across the globe throughout the year 2005. Increasing demand especially from countries like China and India, geopolitical features across the world especially in Middle Eastern region and weather related supply shocks have fuelled the continual rise in crude oil prices. The cost of gulf oil, which was US$17 per barrel at the end of 1999, had reached US$35 per barrel by the end of 2004. By the middle of 2005 the price stood well over US$60 per barrel. Oil prices have especially skyrocketed after July 2005 for various reasons.

The crude oil prices are extremely sensitive to a number of geopolitical factors. Political unrest, military conflicts or extreme weather events, all have played their role in causing rapid rise in global oil prices. Having a look at Fig. 7 it is evident that several such issues like yom Kippur War (1973), Iranian Revolution (1979), Iran/Iraq War (1980), First gulf War (1991), unrest in Venezuela (2002) and Second Gulf War (2003) have all contributed to a rapid increment in crude oil price. The oil prices were noticed to make an immediate jump from US$57 to more than US$65 at the news of the death of King Fahad—the late king of Saudi Arabia. Natural catastrophes have started emerging as another crucial element in the price game—the US hurricane Katrina caused prices to rise to an all time record high, almost US$72/barrels shown in Fig 7.

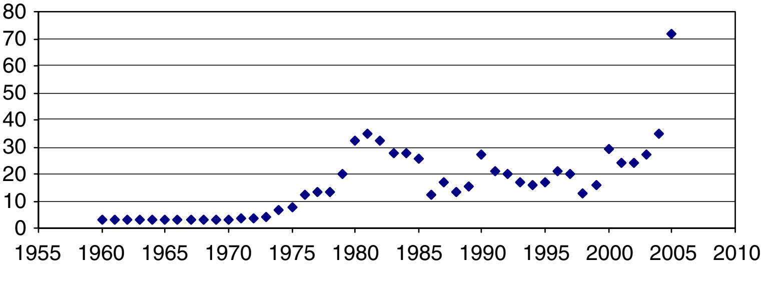


Fig. 7. Historic price trend (in US$/barrel) for crude oil.

The global demand for oil is continuously increasing especially after the growth trend, of some of the emerging economies of the world such as China and India that started appearing towards late 1990s. The production capacity on the other hand is facing the reverse trend. It has been observed that the loss of production capacity of various oil rich countries in the world such as Iraq and Venezuela combined with increased production to meet growing international demand led to the erosion of excess oil production capacity. In mid 2002, there was over 6 million barrels per day of excess production capacity, but by mid 2003 the excess was below 2 million. During much of 2004 and 2005 the spare capacity to produce oil has been less than one million barrels per day. A million barrels per day is not enough spare capacity to cover an interruption of supply from almost any OPEC producer [21]. In a world that consumes well over 70 million barrels per day of petroleum products that adds a significant risk premium to crude oil price.

5. The crucial energy economies

5.1. China

China was the world's second largest consumer of petroleum products in 2004, having surpassed Japan for the first time in 2003, with total demand of 6.5 million barrels per day. The Chinese energy market is dominated by coal, meeting almost 58% of the total primary energy demands in the country. Renewable energy is contributing up to 7% of the energy needs. China's oil demand is projected by EIA to reach 14.2 million bbl/day by 2025, with net imports of 10.9 million bbl/day [22]. China's dependency on energy imports is consistently increasing as shown in Fig 8. As the source of around 40% of world oil demand growth over the past 4 years, with year-on-year growth of 1.0 million bbl/day in 2004, Chinese oil demand is a key factor in world oil markets.

There is enormous potential for renewable energy in China. Renewable energy is seen as crucial and there is enormous international interest in China's potential as a huge market for wind power and other renewable energy technologies. China has similarly huge potential for solar, wave, tidal and biomass power and with energy efficiency could meet all its needs solely from clean energy. By 2004, China has been equipped with 110 GW installed hydropower capacity, 760 MW installed wind power capacity in 43 interlinked plants, and about 60 MW solar photovoltaic batteries. Solar energy water heaters cover 65

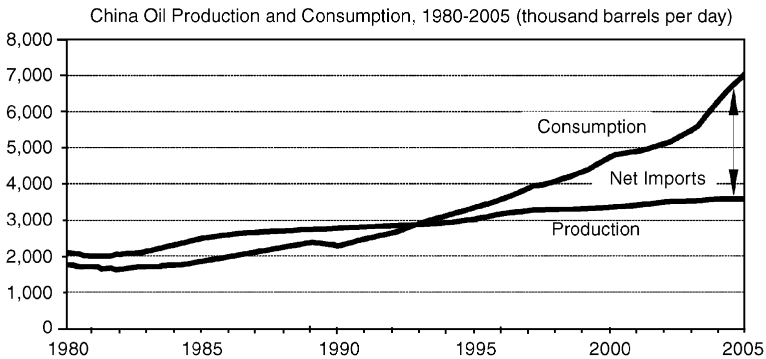


Fig. 8. China's oil production and consumption (1980–2005), thousand barrels per day.

Table 4
Expected growth of renewables in China under the new law

Sector	Current capacity (end 2004) (MW)	Expected capacity in 2020 (MW)
Wind power	560	20,000
Solar energy	50	1000
Biomass	2000	20,000
Hydro power	7000–8000	31,000

million square meters, accounting for more than 40% of the world's total. Moreover, China has built over 11 million household biomass pools in rural areas and around 2,000-odd large and medium-sized biomass projects, with annual fuel output reaching 5.5 billion cubic meters [23].

Renewable energy is developing rapidly in China, with an annual growth rate of more than 25%, the highest in the world. The growth of the wind energy in China in 2004 was 35%. In February 2005, China has approved its renewable energy promotion law. According to the plan by 2015, China will annually develop new and renewable energy resources amounting to 2% of the country's total energy consumption [24]. The renewable energy targets, set under the new law, to be achieved by the year 2020 have been highlighted in Table 4.

5.2. India

India accounted for 3.5% of world primary consumption and 12% that of total primary energy consumed in Asia-Pacific region in 2002 [25]. The country is the world's sixth largest energy consumer and indeed a net energy importer. India is a vast country with diverse mix of resources. The energy consumption is attributed to a number of fuels with varying use patterns. Coal dominates the energy mix in India, meeting about 60% of energy requirements in the country. Nearly 30% of India's energy needs are met by oil, and more than 60% of that oil is imported. Natural gas has experienced the fastest rate of increase of any fuel in India's primary energy supply. Presently, the natural gas contribution is met entirely by domestic production. However, the gap between demand and supply is set to widen unless major gas discoveries are made. It is expected that by 2010 almost three-quarters of India's oil and gas needs will be met by imports [26].

For India to tackle the economic and environmental challenge of its energy demand growth it is important to have a good understanding of how these and other factors shape energy use in various sectors of the economy. Detailed and coherent information is needed in order to judge the potential for energy efficiency improvements or to measure the progress of already implemented policies. India's rapidly growing economy will drive energy demand growth at a projected annual rate of 4.6% through to the year 2010 [27]. It has been reported that India's electric power demand are likely to increase threefold by the year 2051. Indications are that the electric power demand is expected to grow at around 10% per annum in next 15 years requiring about 10,000 MW of capacity addition every year over this period [28]. Other studies indicate that by 2020, India's demand for commercial energy is expected to increase by a factor of 2.5 [29]. Underpinning this trend

will be the ongoing growth in population, urbanization, industrial production and transport demand.

Energy shortages in India have been increasing in the past few years, from 5.9% in 1998/99 to 7.8% in 2000/01. The peak energy demand during 2001–02 touched 86 TWh, of which only 75 TWh could be met. India will continue to experience this energy supply shortfall for at least another 15 years. This gap has been exacerbated since 1985, when the country became a net importer of coal. The growing gap between the demand and supply of energy, and environmental externalities associated with energy use are the key issues today. The energy demand, GDP and population are predicted to increase significantly within the next two decades as shown in Fig. 9. Almost half of India's trade deficit is due to petroleum imports, the cost of which also limits capital that could be invested in the economy [27]. High economic development requires rapid growth in energy sector. This implies substantial increases in electric power generation and transmission capacities, and exploitation of new avenues of energy supply.

Nuclear energy contributes 2% to India's total power generation. Indications are that the share would be even less in 2010 due to many unsolved problems—high cost, radioactive wastes and decommissioning costs [30]. In 2002, India's oil consumption raised to 97.7 million tonnes, more than 2.6 times the domestic production [25]. Estimates indicate that oil imports will meet 75% of total oil consumption requirements and coal imports will meet 22% of total coal consumption requirements in 2006 [30]. India can ill afford to overly depend on fossil fuels considering the high cost of imported petroleum products. India's fossil fuel resources are limited compared to global reserves.

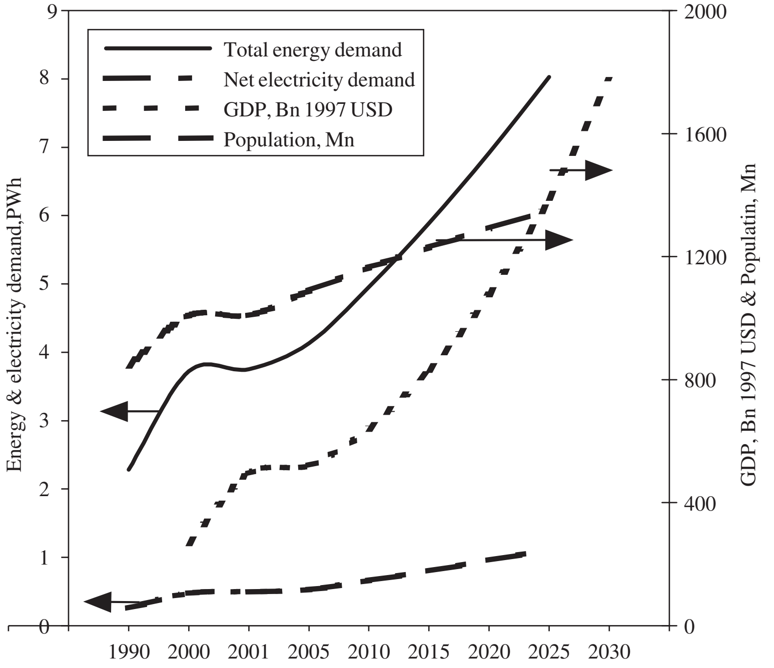


Fig. 9. Energy, economic and population trends for India.

Table 5
Renewable energy potential and achievements in India

Energy sources	Potential	Achievement as on 31.12.2002	India's position in the world
Biogas plants	12 million	3.37 million	Second
Improved chulhas	120 million	33.9 million	Second
Wind	45,000 MW	1702 MW	Fifth
Small hydro	15,000 MW	1463 MW	Tenth
Biomass Power/Cogeneration	19,000 MW	468 MW	Fourth
Biomass gasifiers		53 MW	First
Solar PV	20 MW/sq. km	107 MW_p	Third
Waste-to-energy	2,500 MW	25 MW_e	
Solar water heating	140 million sq.m Collector area	0.68 million sq.m Collector area	

Subscript p stands for peak and e for electrical.

There is a large potential of renewable energy resource available in India, an estimated aggregate of over 100,000 MW, which needs to be harnessed in a planned and strategic manner to mitigate the gap between demand and supply. In the present scenario renewable energy is contributing to about 3.5% of the total installed electric capacity of about 3700 MW. It is planned to increase this to 10% of the total power generation capacity by the year 2012. Today India has the largest decentralized solar energy programme, the second largest biogas and improved solar stove programmes, and the fifth largest wind power programme in the world. Table 5 describes India's renewable energy potential and achievements [31]. However, only a fraction of the aggregate potential in renewables, and particularly solar energy, has been utilized so far. The achieved wind power capacity is less than 4% of the potential from this source. Similarly, the respective installed biomass power and small hydropower capacities are about 2.4% and 9.8% of their potential.

5.3. Russia

Russia has proven oil reserves of 60 billion barrels, most of which are located in Western Siberia, between the Ural Mountains and the Central Siberian Plateau. Approximately 14 billion barrels exist on Sakhalin Island in the far eastern region of the country, just north of Japan. In the 1980s, the Western Siberia region, also known as the "Russian Core," made the Soviet Union a major world oil producer, allowing for peak production of 12.5 million barrels per day in 1988 (most of which came from Russia). Following the fall of the Soviet Union in 1991, oil production fell precipitously, reaching a low of roughly 6 million bbl/day, or around one-half of the Soviet-era peak. Several factors are thought to have caused the decline, including the depletion of the country's largest fields due to state-mandated production surges and the collapse of the Soviet central planning system [32].

With the exception of hydropower, Russia's utilization of renewable energy sources remains low relative to its consumption of fossil fuels. Of the country's 206 GW installed power-generating capacity, hydropower accounts for 22% of the total, with 44.7 GW of installed capacity. Russian hydropower plants generated 173.5 TWh of electricity in 2001, accounting for 20.5% of Russia's total power output of 846.5 TWh for the year. Almost 75% of Russia's hydroelectric capacity is located at 11 power stations with more than

1000 MW of capacity each, including the 6,400 MW Sayano–Shushenskaya facility in the Krasnoyarsk province, the country's largest power plant. Russia's Unified Energy Systems (UES) is building a number of mega-hydropower projects in the Far East as well, including the 3000 MW Boguchansk in Krasnoyarsk and the 2000 MW Bureya hydropower plant. Russia's use of other renewable energy resources is quite small though. The Kamchatka Peninsula in the Far East has rich geothermal resources, and an estimated 380–550 MW of potential geothermal capacity potentially could be exploited there. The first phase of the 200 MW Mutnovskaya geothermal power plant on the Kamchatka Peninsula was put into service in 2002, with the European Bank for Reconstruction and Development (EBRD) providing approximately $100 million in financing for the project [32].

5.4. United Kingdom

The United Kingdom (UK) is an important political and economic power in Europe and the world. It has the second-largest economy in the European Union (EU) with a nominal 2004 gross domestic product (GDP) of $2.12 trillion. The UK economy grew by 3.1% in 2004, one of the fastest rates in the EU. Over the past 5 years, the UK economy has grown much faster than the rest of the EU, averaging 2.6% real GDP growth per year, versus 2.0% per year for the EU as a whole.

The UK is the largest producer of petroleum and natural gas in the EU. However, after years of being a net exporter of both fuels, analysts predict that the UK will become a net importer of these fuels by the end of the decade. Production from UK oil and natural gas fields peaked in the late 1990s and has declined steadily over the past several years, as the discovery of new reserves has not kept pace with the maturation of existing fields.

The UK government has introduced regulations that require electricity distributors to source a portion of their electricity supply from renewables, currently 3% but set to rise to 10% by 2010. Reports indicate that UK power companies planned to construct over 21 GW of renewables capacity by 2010, which would meet 14% of the country's electricity consumption forecasted for that year. Investments in wind power have increased substantially, aiming to take advantage of the natural geographic advantage that the UK has in this regard [32]. Wind energy is seeing a consistent growth in the UK. In June 2005, UK passed the 1000 MW mark with the commissioning of Cefn Croes in Wales, the largest operating onshore wind farm in the UK, making the UK only one of eight countries around the world to have installed over 1000 MW of capacity. With the two new off shore wind farms under construction, the UK will become the world's number one offshore wind generator [33].

There is also a good potential for harnessing solar energy in UK. It has been estimated that the annual solar energy incident on UK buildings (1614 TWh) exceeds the country's peak oil production (1504 TWh). Likewise the UK electricity consumption is 300 TWh and the potential for solar electrical generation is 200 TWh [17,34]. Another area of increased interest has been wave power. In 2004, the Pelamis project off the coast of Orkney delivered the first ever supply of electricity from wave energy to the UK national grid.

5.5. USA

The United States is the world's largest consumer of energy, accounting for 24% of total world energy consumption. United States heavily relies on fossil fuels—approximately

86% of the total energy demands are met by fossil fuels [6]. The country is a major importer of energy and is the world's largest source of greenhouse gas emissions. It is the world's second largest producer of coal after China and the second largest producer of natural gas after Russia. It is also a major producer of oil, representing 9% of the global production and nuclear energy, accounting for 31% of global nuclear electricity production. Major energy consumption sectors in US include residential, commercial, industrial and transportation, which, respectively, share 21%, 18%, 33% and 28% of the total energy. Motor gasoline is the single largest petroleum product consumed in the United States. Its consumption stood at 9.1 million barrels per day in 2004, 44% of all petroleum consumption.

Approximately 30% of the total energy demands of the US are met through imports as shown in Fig. 10 [22] The US crude oil imports grew rapidly from mid-century until the late 1970s but fell sharply from 1979 to 1985 due to conservation efforts and improved efficiency. After 1985, the upward trend resumed and reached a record-high level of 10 million barrels per day in 2004. Petroleum product imports were 2.9 million barrels per day in 2004. The US dependence on oil imports is especially large, at 53% of all consumed. Given that approximately 20% of oil imports are from the Persian Gulf and another 40% from OPEC, US energy markets are much dependent on the politics of the Middle East. The country has also become a net importer of natural gas.

6. Discussion and conclusions

The global energy supply is facing an array of severe challenges in terms of long-term sustainability, fossil fuel reserve exhaustion, global warming and other energy related environmental concerns, geopolitical and military conflicts surrounding oil rich countries, secure supply of energy and fuel price increase. Renewable energy sources are capable of meeting the present and future energy demands with ease without inflicting any considerable damage to global ecosystem. Renewable energy sector, currently meeting 13.5% of the global energy demand, is now growing faster than the growth in overall

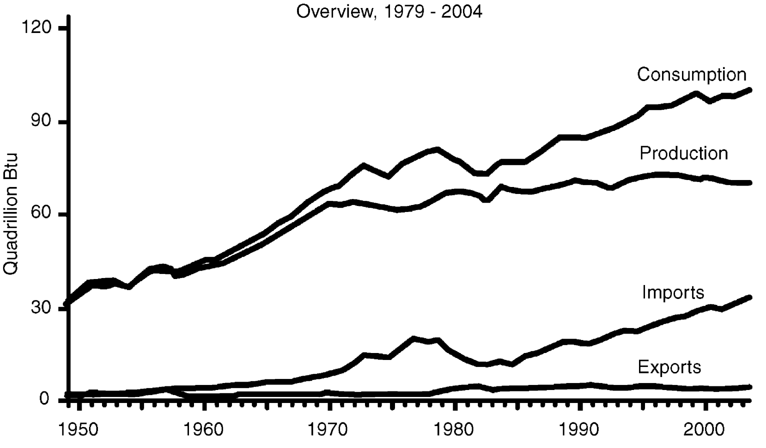


Fig. 10. Increase in import dependency for the US.

energy market. Some long-term scenarios postulate a rapidly increasing share of renewable technologies. Under these scenarios, renewables could reach up to 50% of the total share of mid-21st century with appropriate policies and new technology developments. A large number of renewable-based activities are being undertaken on national and international platforms around the world. European solar thermal market, for example, has grown by a factor of 5 over the last two decades—installed collector area increased from 3,00,000 m^2 in 1984 to 1,50,000 m^2 in 2004 as shown in Fig 11.

The five candidate countries chosen for this study are amongst the top seven energy-consuming nations in the world. They alone are responsible for consuming 49% of the world's total energy. The United States of America and the United Kingdom, respectively, are the first and fourth largest economies in the world. China and India jointly constitute almost one third of the world's entire population and have fast growing economies. Russia is amongst the leading economies of the world and is an oil rich country—in 2004 Russia was second largest oil producing nation in the world after Saudi Arabia with a capacity of 8.8 million barrels/day. Four out of the five countries studied in the present work, China, India, UK and USA, are all net importers of energy and heavily depend on fossil fuel to meet their energy requirement as shown in Fig 12. Their local fossil fuel reserves are close to exhaustion. For example, China, India, UK and USA have local oil reserves that will only last 9, 6, 7 and 4 years (as shown in Table 6), respectively.

The UK has pledged to increase its present capacity of renewable energy production, 3% in 2004, to 10% and 20%, respectively, by the year 2010 and 2020. China is seeing renewable energy as playing an active role in its future energy scenario. China has renewable energy growing at an exemplary pace in the world—in 2004 renewable energy in China grew by 25% against 7–9% growth in electricity demand. While in the same year, wind energy in China saw a growth of 35%. China is also leading the global solar thermal market as it has already installed solar collectors over 65 million square meters, accounting for more than 40% of the world's total collector area. India, having immense potential for renewable energy, has also taken steps to utilize the immense potential for renewable energy sources. The goals of Indian energy planning include the promotion of decentralised energy technologies based on renewable resources in the medium term, and the promotion of energy supply systems based on renewable sources of energy in the

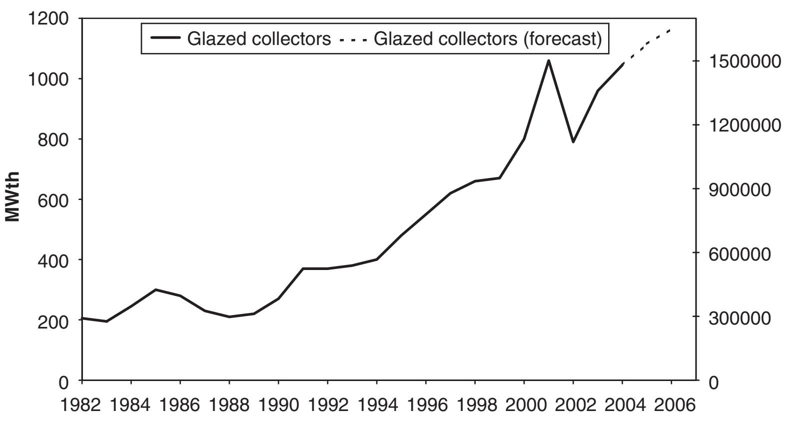


Fig. 11. Solar thermal market in the EU.

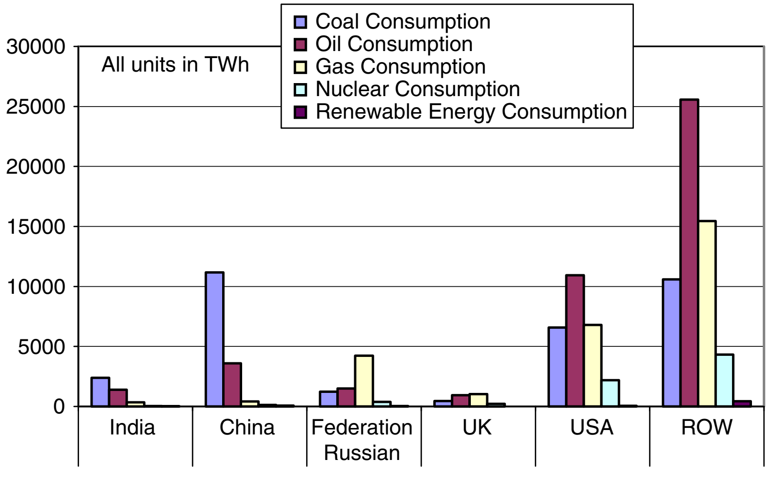


Fig. 12. Energy use for the five key nations by fuel type.

Table 6
Energy reserves and years to exhaustion of non-renewable fuels for five key nations

Total reserves, PWh	India	China	Russian Federation	UK	USA
Coal	752	932	1278	2	2007
Oil	9	39	96	7	44
Gas	8	17	470	6	54
Nuclear	6	5	22	n/a	52
Years to exhaustion (based on a compound growth rate)					
Coal	190	34	112	5	84
Oil	6	9	36	7	4
Gas	22	24	49	6	7
Nuclear	110	22	34	n/a	19
Years to exhaustion (based on a nil growth rate)					
Coal	315	83	1034	4	305
Oil	6	11	64	7	4
Gas	22	41	111	6	8
Nuclear	140	40	57	n/a	24

long-term. Several states within the US are fast developing renewable energy programmes with California leading the way towards hydrogen economy.

Refer to Fig. 4 where it was shown that solar and wind energy provide a solution of complementarity. The energy density that is available for the five nations under discussion is shown in Table 7. Also shown within the same table is the interception area required for the two sources of renewable energy to meet the energy needs for the year 2020. Note that once wind energy has been extracted by means of employing a wind turbine, lower wind speeds result on the downstream side of the machine. Thus a wind turbine that is directly downstream of an upstream machine will not yield its rated power. To overcome estimation errors related to power production of wind farms, the term 'array losses' has

Table 7
Solar and wind farm sizing

	China	India	Russia	UK	USA
Thermal energy requirements for 2020, TWh	27,741	6021	11,118	2903	32,173
Electrical energy requirements for 2020, TWh	3781	909	1669	456	5529
Available solar energy, kWh/m^2-year reference	2021	2599	1444	1155	2887
Annual-average wind speed, m/s	7.2	5	9.0	12.0	12.0
Efficiency of wind turbine	0.2	0.2	0.4	0.4	0.4
Available wind energy per square metre of intercepted area, kWh/m^2-year	118	39	460	1090	1090
Solar/wind generation ratio	3/2	3/2	1/1	1/4	1/4
Solar PV farm size for generating required electricity, km^2	61	26	44	16	36
Solar thermal collection farm size for generating required thermal energy, km^2	131	54	98	56	118
Total area of interception required by wind turbines, km^2	80	68	30	13	45
No. of nominally rated wind turbines of 5 MW capacity	6409	5430	2409	1034	3602
Wind farm size for generating required electrical energy (length), km	45	42	28	18	34
Wind farm size for generating required electrical energy (breadth), km	25	23	15	10	19

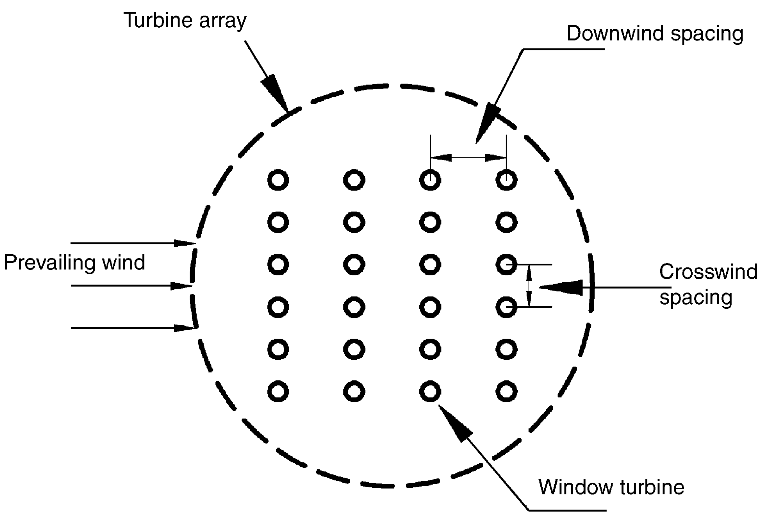


Fig. 13. Wind farm array schematic.

been introduced in the literature. Fig. 13 shows a schematic of the layout of a wind energy farm that may be situated either onshore or offshore. Manwell et al. [35] have shown that for turbines that have downward and crosswind spacing of up to 10- and 5-rotor diameters, respectively, the array losses are typically less than 10% [35].

Using the latterly mentioned pitch and utilizing wind speed data available from Ref. [36] Table 7 has been prepared to provide information on the size of respective wind- and solar-farms that would be required for the five countries under discussion to meet their year 2020 energy demands. In the preparation of these tables it has been assumed that only 50% of the energy needs will be met by the proposed renewable energy farms, with the rest of the demand being met by either decentralized renewable energy production and/or other sustainable means such as hydroelectric or bio-mass based projects. Furthermore, bearing in mind the availability of a given resource, i.e. wind or solar for any given country and also keeping the relevant future economics of the two resources a solar/wind generation ratio has been proposed within Table 7. Note that for countries such as India and China, with low wind regimes it is proposed that multi-blade turbines with low cut-in speeds be utilized. The consequential lower efficiencies from such machines have duly been considered in this study as Table 7 indicates.

Note that the proposed area for collection of solar and wind energy by means of ultra-large scale farms in fact will occupy a mere fraction of the available land and near-offshore area for the respective countries, e.g. a solar PV electricity farm of 61 km^2 for China represents 0.005% of the Gobi desert. Likewise, the 26 and 36 km^2 PV farm area, respectively, required for India and the US represents 0.01% and 0.014% land area for Rajasthan and Baja deserts. The above areas required for the farms may be further split to form a cluster of smaller energy farms.

It is therefore concluded that with increasing concern regarding climate change, depleting fossil fuel reserves and human quest for development of cleaner forms of energy and ingenuity, a switch over to renewable energy sources is quite achievable.

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